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Visual Survey of Apache Aviators (VISAA)

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A three-part study was conducted to assess the visual status of AH-64 pilots. The first part consisted of an anonymous questionnaire returned by 58 Fort Rucker instructor pilots. More than 80 percent of the pilots registered at least one visual complaint (visual discomfort, headache, double vision, blurred vision, disorientation, or afterimages) associated with flying or after flying the Apache aircraft. Many of their comments indicated that symptoms occurred during long flights and/or flying with poor quality or out-of-focus display symbology.

In the second part of this study, a comprehensive visual functions test battery was completed on 10 volunteer, highly experienced AH-64 aviators. The visual function testing included assessments of visual acuity, contrast sensitivity, color vision, depth perception,

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sighting preference, binocular rivalry, and clinical optometric tests of manifest and cycloplegic refractions, accommodative function, and oculomotor status. None of these measures related to a visual complaint index. Differences between the left and right eye were small in all cases. There was evidence of mild incipient presbyopia in many of the pilots, but this is within expectations for the age group (32 to 44 years). Binocular ocular motility for the group as a whole was found to be lower than expected.

In the third part of this study, measurements were made on the flight line of the Helmet Mounted Display diopter focus settings made by Apache IPs and students. The diopter settings ranged from 0 to -5.25 with a mean of -2.28. The required positive accommodation by the eye to offset these negative focus settings is very likely a source of visual discomfort and headache during and after long flights.

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SSG John S. Martin measured the dioptric settings of the helmet mounted display system;

Mr. Parley P. Johnson, Jr., developed the microprocessor system for acquiring the binocular rivalry data.

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Executive summary

A study of AH-64 Apache pilots was conducted to address the visual medical concerns associated with flying this aircraft. This study consisted of three parts, each addressing a separate aspect of Apache aviator vision. The first part, accomplished by written questionnaire, was primarily an epidemiological appraisal documenting current visual problems experienced by the Fort Rucker Apache instructor pilot (IP) population. The second part was a clinical and laboratory evaluation of the refractive and visual status of a sample of these aviators. The third part assessed the Apache pilots' adjustment of the dioptric settings of the Integrated Helmet and Display Sighting System (IHADSS). Because the IHADSS is designed to have the virtual imagery appear at optical infinity, incorrect diopter adjustment could result in sustained accommodation which, in turn, could lead to visual fatigue and subsequent related visual symptomology.

Part 1. Anonymous questionnaire

A brief questionnaire was forwarded to the 14th Aviation Regiment, Fort Rucker, to be distributed to the Apache IP population. A total of 58 were completed and returned. In order to elicit unguarded responses, the questionnaire was completed anonymously.

A. Demographic information: *

Years of age:	Mean:	35.8	Range:	26-44
Years of service:	Mean:	15.3	Range:	4-24
Total flight hours:	Mean:	3330	Range:	1000-9000
AH-64 flight hours:	Mean:	664.4	Range:	150-5000 (N-55)
AH-1 flight hours:	Mean:	1707	Range:	150-5000 (N=54)
AH-64 hours Within last 30 days:	Mean:	32.3	Range:	2-60

Percent of recent time at each crew station:	Pilot -- Mean: 20%	Range: 8-96%
	CPG Mean: 80%	Range: 10-100%
Night vision goggle qualified:	Yes: 51 (88%)	No: 7 (12%)
Eyeglass wearers:	Yes: 20 (34%)	No: 38 (66%)

* N=Number of Response (58 unless noted otherwise)

B. Visual symptoms reported by Apache pilots during and after Apache flight:

More than 80 percent of the pilots registered at least one visual complaint associated with flying or after flying the Apache aircraft. Many of their comments indicated that symptoms occurred during long flights and/or flying with poor quality or out-of-focus display symbology. The most common symptom experienced was that of visual discomfort while flying the aircraft. Fifty-one percent of the pilots indicated that they sometimes experienced visual discomfort while flying; only 28 percent reported a similar problem after flying. About one-third of the aviators reported suffering from occasional headaches and about 20 percent responded that they sometimes experienced either blurred vision and/or disorientation while flying. The percentages of pilots reporting headache and blurred vision remained about the same after flight,while the percentage of those experiencing post flight disorientation decreased to five. About 20 percent of all pilots reported the presence of afterimages following Apache flight. The actual percentages of pilots reporting symptoms are shown in Table 1; a sampling of their pertinent comments follows the table.

Table 1.

Percentages of pilots reporting visual symptoms during
and after Apache flight

	During flight			After flight		
	Never	Sometimes	Always	Never	Sometimes	Always
Visual Discomfort	49%	51%	–	70%	28%	2%
Headache	65	35	–	67	32	2
Double vision	86	12	2%	89	9	2
Blurred vision	79	21	–	72	24	3
Disorientation	81	19	–	95	5	–
Afterimages	NA	NA	NA	79	19	2

During flight comments

-- Occasional eye strain due to poor FLIR [forward looking infrared] quality on some flights when the system is used extensively (visual discomfort).

-- on PNVS flights of more than 3 hours (visual discomfort).

-- If the FLIR image is out of focus, of poor quality, or if the HDU [helmet display unit] is out of focus, severe right eye pain for up to several hours (headache).

-- When using the HDU (day gunnery or night flight), headaches occur followed by vision problems. Problems may be due to my inability to obtain an "infinity focus" on the HDU symbology or the system not maintaining the focus that I've set (headache).

-- After removing the combiner lens from the right eye things are blurred for 4-5 minutes (blurred vision).

-- Occasional, mild, when switching rapidly between the left (unaided) and right (aided) eyes to resolve an object in the field-of-view (disorientation).

<u>After flight comments:</u>

-- Occasionally, after long PNVS [pilot night vision system] flights of greater than 3 hours, I experience eye strain or "soreness" in my right eye which persists until I go to sleep (visual discomfort).

-- After 3-4 hours of system flying under PNVS (headache).

-- After flying the night system, my right eye has blurred vision for about 45 minutes (blurred vision).

-- After long flights (>2.5 hours) with poor quality FLIR, some afterimages can occur for up to 2-3 hours after the flight. This is most noticeable in a dark room such as when going to bed after a training day.

C. Additional visual problems:

Fifteen pilots (26 percent of the sample) reported changes in their ability to see or interpret HMD [helmet mounted display] symbology during flight. All but two of those claimed that their abilities worsened. About 70 percent of all pilots used the affirmative categories (Always, Usually, Sometimes) when asked if their vision ever alternated <u>unintentionally</u> between the two eyes either during or after Apache flight. Of the 20 self-reported spectacle wearers, only 11 responded to the question of whether the use of the modified spectacle interfered with the ability to see HMD symbology; of those, however, 10 responded that the spectacles interfered with viewing and reported significant discomfort from their wear.

D. Additional aviator comments

Pilots were asked to provide comments on any other visual or ocular symptoms experienced with the Apache IHADSS, apart from those questions contained in the questionnaire. Some of their responses are listed below:

-- After long periods on PNVS operations and consecutive nights, I have problems with focusing distant objects with the right eye.

-- After an extended period of HDU use, the right eye is not night adapted while the left eye is. After rotating the HDU out of the way, you are essentially night blind in the right eye and night adapted in the left eye. This causes slight sensations of imbalance and loss of depth perception until the right eye adapts several minutes later.

-- I've developed the ability to use each eye separately. I am becoming excessively right-eye dominant. I have to close it when not flying to use my left eye.

-- My right eye appears to be having acuity problems and suffering from strain. My guess would be that during flight with the HDU/HMD, I may not be able to distinguish a proper infinity focus as designed, and I'm continually causing my eye to compensate, causing strain and blurring problems, and causing my acuity to be lost.

Part 2: Laboratory evaluation of 10 Apache aviators

The original design of the study called for two groups of five pilots, one group consisting of individuals who had reported Apache related visual problems to the Flight Surgeon, and a group who had not reported visual problems and were matched in age and in flight experience. Because of temporary duty (TDY) and duty conflicts, and at least one refusal to participate, the individuals identified as having visual problems were by-and-large not available for this study. The sample thus consisted of but a single group of opportunistically selected IPs. They ranged in age from 32 to 44, mean 38.6 years. As a way of distinguishing among the l0 pilots with respect to visual symptoms and complaints, their responses on the questionnaire were tallied. The maximum possible score is ll, and for the present sample the range was from 0 to 4 with a mean of 1.5.

The correlation coefficients for the relationship between the visual complaint score and 32 different measures of visual and ocular status were calculated. None of the correlations were statistically significant. Differences between the right and left eye on the variety of vision and ocular tests were small in all cases. There was evidence of mild incipient presbyopia in most of the pilots, but this is within expectations for the age group. Binocular ocular motility for the group as a whole was found to be lower than expected.

In summary, no significant variation from expected normal values was measured in the ten AH-64 aviators who were subjected to comprehensive visual function testing.

Part 3: Measurement of Helmet Mounted Display (HMD) dioptric focus setting

Twenty Apache aviators served as subjects, 11 students and 9 instructor pilots. Nine subjects were measured under nighttime illumination; the remaining 11 were measured under daytime illumination.

The range of dioptric settings was 0 to -5.25 with a mean of -2.28. The required positive accommodation by the eye to offset these negative focus settings is very likely a source of headaches and visual discomfort during and after long flights. No correlation was found between the focus settings and aviator age or experience; nor were there differences between IPs and students, or day versus night settings.

Prior to the data collection procedure, it was hypothesized that inadequate training in proper procedures for setting the focus of the HMD could very likely result in unnecessarily high negative settings. This is a result of the eye's ability to induce positive power. This hypothesis was borne out by the data and the observed focusing techniques demonstrated by the aviators. The hypothesis was further tested on three subjects by demonstrating to them proper focusing technique and having them repeat the focus setting. The repeat focus settings for all three subjects were between 0 and -1 diopter.

Introduction

The AH-64 Apache aircraft is today's most sophisticated Army attack helicopter. Central to its advanced day-and-night, all-weather capability is its Integrated Helmet and Display Sighting System (IHADSS) which provides forward looking infrared (FLIR) imagery and instrumentation symbology to the pilot's right eye (Figure 1). The pilot's left eye, without electro-optical enhancement, simultaneously views the external world directly. Thus, at any time, the pilot may divide his visual fixation and attention among the three alternative sources of information.

When the IHADSS is used, the optical input to the two eyes differs greatly. This situation, referred to as dichoptic viewing, underlies binocular rivalry, a competition between the two eyes for the information which reaches attention. Rivalry usually is resolved by suppressing visual input unilaterally, and attention may alternate spontaneously between the views received from each eye. Such dichoptic viewing, under sustained periods of monocular viewing and suppression, places great demands on the visual system and may be expected to result in high workload and stress levels.

Figure 1. AH-64 Apache pilot wearing the IHADSS

In a recent survey of AH-64 Apache pilots, Hale and Piccione (1989) reported that flying the IHADSS at night often led to physical fatigue and headaches. Among the causes they identified, in addition to monocular viewing and binocular rivalry, were poor FLIR image quality, narrow field-of-view, poor depth perception, inability to detect distant targets under adverse thermal conditions, inadequate eye relief, and general system discomfort. Similar complaints by Apache instructor pilots (IPs) have been reported to flight surgeons and unit commanders at Fort Rucker, and have raised concern about long-term medical effects. The existence at Fort Rucker of a large population of AH-64 Apache aviators offered the opportunity to examine whether high flying hours in this aircraft, especially with the monocular IHADSS, resulted in measurable changes in visual function. A study was formulated, therefore, to address the visual medical concerns associated with flying this unusual aircraft system.

This study consists of three parts, each addressing a separate aspect of Apache aviator vision. The first part, accomplished by written questionnaire, is primarily an epidemiological appraisal documenting current visual problems experienced by the local Apache pilot population. The second part is a clinical and laboratory evaluation of the refractive and visual status of a sample of these aviators. The third part assesses the Apache pilots' adjustment of the dioptric settings of the IHADSS. Because the IHADSS system is designed to have the virtual imagery appear at optical infinity, incorrect diopter adjustment could result in sustained accommodation which, in turn, could lead to visual fatigue and subsequent related visual symptomology.

Part 1: Epidemiological appraisal

A questionnaire, a copy of which is presented in Appendix A, was designed to elicit information in three main areas of interest: (1) aviator demographics and experience (questionnaire items 1, 2, 4a-d), (2) visual history and laterality (items 3a-i), and (3) current flight-related visual problems (items 4d-l). An additional series of questions (items 4m-q), appended to the questionnaire, queried spectacle wearers on their acceptance and use of an aviation spectacle frame modified for Apache aviators. In order to elicit unguarded responses, the questionnaires were completed anonymously.

Sample size and response rate: A total of 58 questionnaires were distributed to the Apache IPs and returned. Not all the respondents answered all questions; however, the response rate for each question was 90 percent or more. Discrepancies from the full data set are noted where appropriate.

Results: The questionnaire results are presented according to the categories described. Section A summarizes the demographic and aviation experience of the sampled aviators. Section B briefly sketches their visual histories and provides data on hand and sighting eye dominance. Section C, the main thrust of this investigation, provides data on current visual problems, especially those experienced during and after flight in the AH-64. It also contains information on IHADSS fit and on visual problems associated with the helmet mounted display (HMD). A final section, Section D, summarizes the responses of ametropic aviators to questions on the use of the modified aviator spectacle and its compatibility with visual requirements in the Apache aircraft.

A. Pilot demographics and aviation experience:

Demographic data for the 58 Apache IPs are presented in Table 2. Table 3 summarizes their aviation qualifications and flight hours in aircraft other than attack helicopters. Table 4 presents their experiential and qualification data in the AH-64, the AH-l, and with night vision goggles (NVGs). Distributions of aviator ages, years of military service, and years flight rated are displayed graphically in Appendixes B, C, and D. Distributions of total hours flown in all aircraft and in the AH-64 Apache are shown in Appendixes E and F.

Table 2.

Demographic data and aviation experience

	Years of age	Years of service	Years rated	Total flight hours
Mean	35.8	15.3	12.6	3330
S.D.*	4.0	4.4	5.3	1625
Range	26-44	4-24	3-23	1000-9000

* S.D. = Standard deviation

Table 3.

Aircraft flight hours: Nonattack aircraft *

	No. of pilots	Mean flight hrs.	Range
TH-55	17	81	30-200
OH-6	7	674	100-2000
OH-58	24	367	50-1000
UH-1	50	761	50-5000

* Flight hours were reported also in the following aircraft: CH-54, 1 pilot, 100 hours; T-41, 2 pilots, 50 and 360 hours, respectively; T-42, 1 pilot, 200 hours; U-8, 2 pilots, 250 and 1500 hours, respectively; and U-21, 3 pilots, 150, 250, and 400 hours respectively. No additional aircraft hours, including civilian, were reported.

Table 4.

AH-l, AH-64, and NVG qualifications

	Mean	SD	Range
No. of months AH-64 qualified	30.1	18.6	8-96
Total AH-64 flight hours*	664.4	385.0	150-1500
Total AH-1 flight hours**	1707.0	910.6	150-5000
AH-64 flight hours in the last 30 days	32.3	12.8	2-60
Percentage of time recently flown in the:			
Pilot's position	20.4	21.9	0-90
G/CP's position	79.7	21.6	10-100
NVG qualified (Y/N)	Y=51 (88%)	N=7 (12%)	

* Number of respondents = 55
** Number of respondents = 54

As might be expected from a sample of high-performance aircraft IPs, the respondents can be characterized as a group of highly experienced Army aviators. (More than two-thirds of our sample were at least 36 years of age and/or had 15 or more years of military service. Almost half were rated aviators of 15 years or longer.) Nearly all the pilots reported extensive flight time in both the UH-1 and the AH-1. About two-thirds had between 150-750 flight hours in the Apache and almost 20 percent reported as many as 1500 hours of Apache flight time. Because of their work as IPs, most of this sample's recent flight hours were in the aircraft's gunner/copilot's crewstation.

B. <u>Aviator visual history and laterality</u>:

<u>Corrective lenses</u>. About one-third (20) of the aviators reported past or present corrective lens wear. Of these, 18 provided their chronological age when first prescribed glasses and 16 provided the date of their most recent prescription. The prescription dates have been transformed to number of months for purposes of analysis. Table 5 summarizes these data.

Table 5.

Aviator visual history: Corrective lenses

Eyeglasses	Yes=20* (34%)	No=38 (66%)
Years of age when first prescribed eyeglasses (N=18)	Mean: 29.5	Range: 13-42
Age (in years) of most recent spectacle prescription (N=16)	Mean: 2.6	Range: 0-5

* Includes two current contact lens wearers

As shown in Table 5, spectacle wearers averaged about age 30 at the time of their initial prescription. However, half of all corrective lens wearers began wearing correction between the ages of 31-35. Reading/close work and acuity improvement at distance (N=6 each) were the reasons most frequently offered for wearing spectacle correction. Five other pilots indicated that they wore correction for flying only and one claimed to wear eyeglasses habitually. One pilot stated that he required correction initially for reading but now also for flying. (One pilot failed to respond to this question.) Most spectacle prescriptions were relatively current (<2 years) although six individuals claimed their most recent prescription to exceed 3 years. One pilot indicated that, although he was prescribed glasses at age 38, he had achieved 20/20 Snellen acuity on his last flight physical (at age 43), and no longer needed nor wore spectacle correction.
Five pilots indicated experience with contact lenses and two were current wearers (under waiver as subjects in a research study).

Eye injury/disease and visual disorders. Ten pilots reported treatment for eye disease or eye injury, but only one (with toxoplasmosis) within the past 6 years. Eye strain and temporary reduced acuity (blurred vision), however, were reported by more than 70 percent of the sample, including five individuals who reported both (Table 6). Although the primary aim of these questions was to elicit nonflight visually-related problems, more than half of the eye strain/visual discomfort respondents associated these symptoms with night flying using the "system" (i.e., the AH-64's Pilot's Night Vision Sensor [PNVS] and/or the gunner/copilot's Target Acquisition and Designation Sight [TADS] systems). This is in contrast to the others who conformed to the questions' original intent and attributed their temporary blurring to reading, close work, driving, bright light, and other nonjob related activities (Table 7).

Table 6.

AH-64 aviator visual histories

Visual problem	N*	Yes	No
Have you ever been treated for an eye disease or eye injury?	54	10	44
Have you ever experienced double vision?	57	8	49
Have you ever experienced temporary reduced visual acuity (blurred vision)?	57	15	42
Do you get headaches from extended periods of close work, for example, reading small	57	6	51
Do you ever experience eye strain?	56	36	20

* Number of respondents

Table 7.

Blurred vision and eye-strain among Apache aviators:
Subjective causes and frequencies (N=47)

Response	No. of responses
Flying with the PNVS/TADS	24 (51%)
Studying/reading	14 (30%)
Driving	2 (4%)
Other	7 (15%)

Laterality. Table 8 presents data on hand and eye preferences. As shown, most respondents reported preferences for both the right hand and eye, although based upon their responses to these questions, the eye chosen for a particular sighting task could be considered task dependent. Six of the right-eyed dominants reported a change in sighting preference (presumably from left to right) as a result of their Apache flight training. Although post hoc analyses indicated that left-eyed dominant aviators were no more likely than right-eyed dominants to experience visual problems in the cockpit, five of the six former left-eyed dominants registered two or more visual complaints either during or after flying (see complaint categories in Sections C2 and C3, below).

Table 8.

AH-64 aviator eye and hand preferences

Sighting eye preference	Left	Right	Equal	??*
Which is your better eye (preferred sighting eye)?	13	36	3	6
Which eye would you use with a telescope? (N=56)	6	50	N/A	N/A
Which eye would you use to see through a keyhole? (N=54)	11	43	N/A	N/A
Is your better eye the same one as prior to AH-64A training? (N=51)	Yes = 45		No = 6	
Hand preference	Left	Right	Equal	??*
What is your hand preference for ball throwing?	4	54	0	N/A

* ?? = "Don't know" response category

C. Aviation vision:

The data from this section of the questionnaire are presented in the following format: the question as it appears in print, the tabulated responses, and, where appropriate, a listing of selected user comments given in response to the question. A short discussion of trends or conclusions drawn from the responses then follows. User comments were selected primarily on the basis of their frequency but also for their explicitness. (Occasionally, user comments were edited slightly to improve fragmentary responses, verbal lacunae, or misspellings. Places Where this occurs are indicated with square brackets [ ]). Unless noted otherwise, the number of respondents (N) to all questions equals 58.

1. Pilot satisfaction with the IHADSS fit:

How satisfied are you with the fit of your IHADSS helmet? If less than perfectly satisfied, please describe any problem the fit causes.				
	Not at all	Somewhat	Reasonably	Perfectly
N	1	7	36	14
%	2%	12%	62%	24%

Comments:

-- Hot spots at [the] back of [my] head [in] the area of nape strap and forehead band. Slight ear discomfort after 3 hours. (Reasonably satisfied)

-- Tends to rotate on my head when I turn 90 degrees. Increasing helmet tightness results in too many hot spots and headaches. (Reasonably satisfied)

-- Ear cups continually need to be repositioned to fit properly over ears. Stretching or sagging of webbing or liner necessitates readjustment, especially on right side, due probably to [the] added weight of the HDU. (Somewhat satisfied)

-- I have to extend the combiner lens all the way to position it in front of my eye. This greatly reduces the amount of video that can be seen, particularly symbology. (Reasonably satisfied)

-- HDU sometimes contacts my right eye, with the combiner lens sometimes touching [my] right eyeball. (Reasonably satisfied)

Discussion: Nearly all the Apache IPs claimed to be at least reasonably satisfied with their IHADSS fit. Yet this one particular question generated the greatest number of negative comments. An examination of these statements yielded several common areas of dissatisfaction. These have been categorized and listed in Table 9 in the order of their frequency of occurrence. (Most respondents limited their comments to a single category.)

Table 9.
Types and frequency of self-reported IHADSS problems

IHADSS problem	Frequency
-- Headband "hot spots"/headache	13
-- Loose fit/slippage	11
– Ear cups (too small, painful, or insufficient noise attenuation)	8
-- Discomfort from other helmet components (chin strap, buckle, nape strap, etc.)	4
– Restricted field-of-view through combiner	3
– Uncomfortable sensation from combiner touching eyelashes	2

As shown in Table 9, the main sources of IHADSS discomfort were attributable to fit -- either too tight or too loose -- or to the rubbing or chafing of the ears and neck by components of the helmet's retention system. Such discomfort would become increasingly apparent as a function of the duration of flight. While only a few aviators indicated dissatisfaction with the (restricted) view through the combiner, we should recognize that any slippage of the helmet could degrade the alignment of the HDU and subsequently impair the pilot's field-of-view.

2. Visual problems experienced while flying the AH-64A:

While flying the Apache, have you experienced: Visual discomfort? Headache? Double vision? Blurred vision? Disorientation? If other than never, please comment on how often, how long it persists, and how severe it is.			
	Never	Sometimes	Always
Visual discomfort	28 (49%)	29 (51%)	0
Headache	37 (65%)	20 (35%)	0
Double vision	49 (86%)	7 (12%)	1 (2%)
Blurred vision	46 (79%)	12 (21%)	0
Disorientation	46 (81%)	11 (19%)	0

Note: N=58 for "Blurred vision;" N=57 for all others.

Comments: visual discomfort

– During extended PNVS flights, i.e., > 3.5 hours. (Sometimes)

-- Depends upon how long I fly with the PNVS, how the system is operating, and the weather conditions. (Sometimes)

– Under poor FLIR or system conditions. (Sometimes)

– Some eye-strain after 2.5-3.0 hours [of flying]. The amount of eye-strain is related directly to quality of the FLIR image and the duration of having to fly with a poor FLIR image. (Sometimes)

– When using the HDU (day gunnery and night flight). Problems may be caused by my inability to obtain an infinity focus on the HDU symbology or the system not maintaining the focus I have set. (Sometimes)

Comments: Headache

– If the FLIR image is out of focus, of poor quality, or if the HDU is out of focus, [I get] severe right eye pain for up to several hours. (Sometimes)

-- Slight headache, not very often; usually happens only while flying the night system. (Sometimes)

– Minor and not very persistent. Can be caused by out-of-focus FLIR, overcrowded ranges and stagefields, listening to four different radio frequencies, and long flight periods (> 3.8 hours) at night. (Sometimes)

– When flying with glasses, the pressure on the nose and cheek causes discomfort and sometimes headaches, but only when flying with the HDU in front of the eye. (Sometimes)

– During long flight with the PNVS. (Sometimes)

Comments: Double vision, blurred vision, and disorientation

-- Occasional double vision due to poor FLIR quality on some flights when the system is used extensively. (Sometimes)

-- After a period of approximately 10-15 minutes of viewing the HMD video, upon seeing a light source with the left eye, if the HMD is folded away from the right eye, there appears to be two distinct light sources -- one white (left eye), one red (right eye). The two images move together to form one image after approximately five seconds. (Always)

– In the left eye when focusing from inside to outside the cockpit when fatigued during extended PNVS flying. Lasts about five seconds. (Sometimes)

– After removing combiner lens from the right eye, things are blurred for 4-5 minutes. (Sometimes)

– Occasional, mild disorientation that occurs when switching rapidly between the left (unaided) and right (aided) eyes to resolve uncertainty of an object in the field-of-view. (Sometimes)

Discussion: Sixty-two percent of the sampled aviators selected one or more complaint categories to delineate visual problems experienced while flying the Apache aircraft. The distribution of visual complaints, both before and after flight, are shown in Figure 2. Visual discomfort (51 percent) and headache (35 percent) were the two response choices cited most often by the IPs, followed by blurred vision (21 percent), disorientation (19 percent), and double vision (14 percent).

Based upon their recorded comments, nearly all instances of visual discomfort occurred at night -- a possible reason for the extensive use of the "Sometimes", category by those indicating ocular problems. According to the pilots, the most prevalent origin of visual discomfort centered around imagery -- either out-of-focus and/or subjectively poor quality FLIR and/or display imagery. For the most part, however, the discomfort experienced by the aviators was occasional, mild, and transient, although many experienced continued discomfort and headache following flight (see below).

3. Visual problems experienced after flying the AH-64A:

After flying the Apache, have you experienced: Visual discomfort? Headache? Double vision? Blurred vision? Disorientation? Afterimages? If other than never, please comment on how often, how long it persists, and how severe it is:

	Never	Sometimes	Always
Visual discomfort	40 (70%)	16 (28%)	1 (2%)
Headache	38 (67%)	18 (32%)	1 (2%)
Double vision	51 (89%)	5 (9%)	1 (2%)
Blurred vision	42 (72%)	14 (24%)	2 (3%)
Disorientation	54 (95%)	3 (5%)	0 (0%)
Afterimages	45 (79%)	11 (19%)	1 (2%)

Note: N=58 for "Blurred vision;" N=57 for all others.

Comments: Visual discomfort

– Occurs after flying several days on the system; 2-3 hour delay in symptoms. (Sometimes)

– Occasionally after long PNVS flights of greater than 3 hours I experience eye strain or "soreness" in my right eye which persists until I go to sleep. (Sometimes)

– If the FLIR image is out of focus or of poor quality, or if the HDU is out of focus. (Sometimes)

– Brown out -- right eye usually (persisting) 30 minutes. (Sometimes)

– ...when FLIR quality is poor, you constantly strain to see enough detail to fly the system, causing eye strain. (Sometimes)

Comments: Headache

– Almost always occurs after night flying more than about 1-hour. Usually persists 4-6 hours. Severity light to moderate. (Always)

– Occasional moderate headache, lasting 3-4 hours, after night flight of 4.0 hours. (Sometimes)

– If the FLIR image is out of focus or of poor quality, or if the HDU is out of focus, severe right eye pain for up to several hours. Depends on the quality of the system. (Sometimes)

– After 3-4 hours of system flying under PNVS. (Sometimes)

– Depends on how well PNVS system works and the length of the flight. (Sometimes)

Comments: Double vision, blurred vision, disorientat%on, and afterimages.

– Double vision after removing the combiner lens from the right eye. (Sometimes)

– After flying the night system, my right eye has blurred vision for about 45 minutes. (Sometimes)

– After flying a lot of system (nights), I sometimes have right eye-strain with blurred vision for a short time. (Sometimes)

– After long flights (> 2.5 hours) with poor FLIR, some afterimages can occur [for up to] 2-3 hours after the flight. This [is most noticeable] in a dark room such as when going to bed after a training day. (Sometimes)

– Browning of vision in right eye after 3.8 hours of system flight. (Sometimes)

Discussion: As in the "while flying" condition, about 60 percent of the respondents selected one or more visual symptoms post-flight. Once again, headache and visual discomfort were the two most frequently reported visual symptoms, although now reversed in frequency of occurrence (34 percent and 30 percent for headache and visual discomfort, respectively; [Figure 2]). These were followed by blurred vision (27 percent), afterimages (21 percent), double vision (11 percent) and disorientation (5 percent). The reduction in the number of reports of visual discomfort, from 51 percent during flight to 30 percent after, suggests that the condition may be induced situationally by in-flight visual conditions (or that the terminology used in the questign-naire to depict the condition may have been vague and open to individual interpretation). Except for visual discomfort, disorientation (very likely to be interpreted as an in-flight phenomena due to switching attention between the aided and unaided eyes), and afterimages (an appended postflight category), the percentages of positive responses (Sometimes, Always) for each of the remaining visual symptoms were fairly similar both during and after flight.

Based upon the pilots' written comments, the conditions contributing to visual disturbances after flight were markedly similar to those causing problems during flight -- namely, system flight of about 3 or more hours and degraded and/or out-of-focus FLIR and display imagery. In some cases, the visual problems recorded after flight may represent the perseverance of symptoms originating during flight. "Headache," for example, was marked by 15 aviators (who may have endured them) both during and after flight. (Unfortunately, questions of persistence of symptomology initiated during flight were not asked.) In general, however, an examination of the data showed that of the 81 percent of the sample (47 aviators) marking a visual complaint, slightly less than half (23) experienced symptoms both during and after flight. In contrast, more than half reported symptoms that were restricted to the periods either during(13 of 48) or after flight (12 of 48). Thus, while postflight visual disturbances may start while flying and persist thereafter, symptoms also either may dissipate before the end of the flight or become manifest at some time after landing.

4. Visual changes associated with HMD svmbology:

Have you noted any change in your ability to see or interpret the HMD symbology during any phase of flight? If yes, please explain.	
Yes = 15 (26%)	No = 43 (74%)

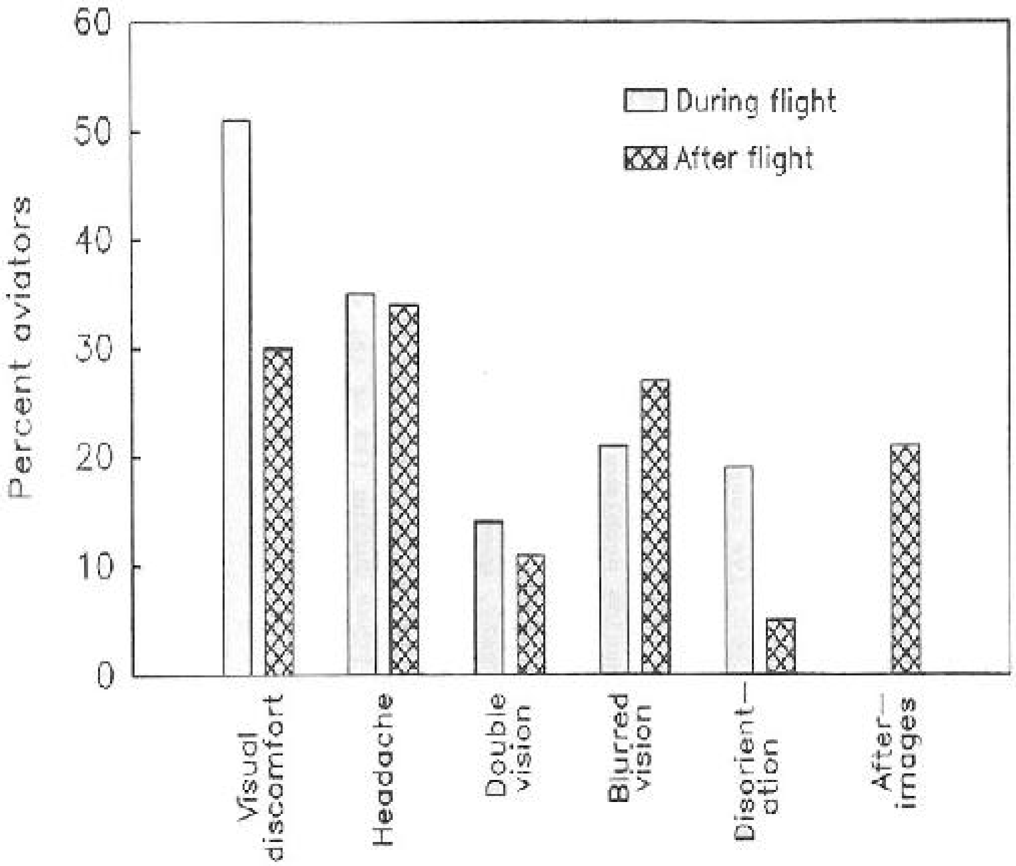

Figure 2. Visual complaints during and after Apache flight.

Comments:

– When] flying with a headache, I tend to rely on FLIR cues rather than symbology to avoid having to focus or interpret symbology. I know [that] symbology should be focused at infinity, but it still strains you somewhat to look at it when you have a headache.

-- No problems in seeing but ... interpretation varies with experience and [is] affected directly by fatigue and mental state.

-- If infinity focus is not done properly at the beginning of flight, eye strain is apparent at approximately 45 minutes into the flight period and symbology becomes harder to keep in focus.

-- After extended use with increased sense of tiredness sometimes the focus in the HDU tends to vary.

Discussion: Approximately one-fourth of the respondents indicated that they experienced some change in their ability to see or interpret the helmet mounted display symbology during flight. Comments accompanying the pilot's responses generally indicated that visual fatigue and/or headache interferes with or often hinders the interpretation of the visual display. However, that a "change" in the ability to detect or discriminate symbology might not always represent impairment is shown by two aviators who remarked that their cognitive abilities improved as a function of experience with the system.

When viewing through the HMD, can you focus clearly on the external scene and symbology simultaneously? (N=57)				
	Always	Usually	Sometimes	Never
N	30	21	4	2
%	53%	37%	7%	4%

Do you have to refocus to view the symbology? (N=55)	
Yes	No
8 (15%)	47 (85%)

Discussion: The helmet mounted display (video/FLIR image and surrounding symbology) is designed to be viewed on a single objective plane (infinity distance) with relaxed accommodation. Most (85 percent) aviators claimed they could accomplish this visual task without having to refocus continually between the symbology display and the video image. However, post hoc analyses indicated one interesting trend -- individuals reporting the need to refocus between the external scene and symbology evidenced an average complaint rate (i.e., the total number of complaints during and after flight [Sections C2 and 3]) twice that of their nonrefocusing counterparts (mean = 4.5 vs. 2.3; median = 3.0 vs. 1.0).

5. Use of the helmet visor:

How do you use your visor? [Day/night]				
	Day		Night	
	Up	Down	Up	Down
N	13	45	52	6
%	22%	78%	90%	10%

Discussion: Most of the Apache IPs tended to use their visors in the daytime and to retract it at night. Because the question was nonspecific with respect to visor type (a shortcoming), we can only assume that daytime visor-users employ their tinted sun visor while those who use their visor at night referred to their clear visor.

6. Unintentional visual alternation during and after flight:

During Apache flight, does your vision sometimes unintentionally alternate between the two eyes?				
	Always	Usually	Sometimes	Never
N	3	3	34	18
%	5%	5%	59%	31%

After Apache flight, does your vision sometimes unintentionally alternate between the two eyes?				
	Always	Usually	Sometimes	Never
N	0	0	18	40
%	0%	0%	31%	69%

Discussion: During flight, Apache pilots using the PNVS/TADS are presented with two disparate views -- one (right eye) via the HDU, the other (left eye) unaided. Nearly 70 percent of the respondents used the affirmative categories (Always, Usually, Sometimes) when asked if their vision ever alternated unintentionally between the two eyes during flight. Thirty-one percent claimed the phenomenon occurred (at least sometimes) after flight. In some individuals, the involuntary visual alternation experienced after flying may represent the persistence of effects begun during flight (43 percent of those reporting binocular rivalry after flight reported the same during flight). Unfortunately, questions relating to the development and temporal course of visual rivalry were not asked. Although the sample sizes were small, post hoc analyses indicated differences in the proportion of right- and left-eyed sighting dominants reporting unintentional visual rivalry both during and after flight– During flight: Right-eyed dominants-80 percent, Left-eyed dominants-61 percent; after flight: Right-eyed dominants-44 percent, Left-eyed dominants-15 percent.

Binocular rivalry generally was, although not invariably, associated with self-reports of other visual problems, both in and post flight (Questions 4e and f). Although it is known whether and which symptoms may be experienced together, 27 of 40 (68 percent) ‘in-flight alternators’ indicated additional visual problems during flight (Question 4e). Indeed, using responses to Question 4e as a basis for comparison, ‘in-flight unintentional alternators’ (as identified in Question 4j) manifested an average ‘while flying’ complaint frequency of more than twice that of their 13 ‘nonalternating’ counterparts (2.03 vs. 0.97). Similarly, 14 of 18 (78 percent) ‘postflight alternators’(Question 4k) also indicated one or more additional visual problems after flying (Question 4f). As in the in-flight condition, the average number of postflight visual complaints for these individuals doubled that of their corresponding 40 ‘postflight nonalternators’ (2.29 vs. 1.05).

7. Other visual or ocular symptoms:

Please comment on other visual or ocular symptoms you have experienced with the Apache IHADSS.

– It seems that my right eye does all the work day and night.

– Feeling of right eye being "bulged" out and also a slight loss of depth perception occurring after the flight. If I fly 5 nights, 3.5 [hours] per [night], I can expect the occurrence of either visual discomfort, headache, blurred vision, or all three.

– After [an] extended [period] of HDU use, [the] right eye is not night adapted while the left eye is night adapted. After rotating [the] HDU out of the way, you are essentially night blind in the right eye and night adapted in the left eye. [This] causes slight sensations of imbalance [and] loss of depth perception until [the] the right eye adapts several minutes later.

– When flying at night under PNVS, my left eye is drawn frequently to ground lights reflecting off the inside of the canopy. This sometimes appears as an unexpected aircraft's position light and gives me a momentarily spooked reaction.

-- I've developed the ability to use each eye separately. I am becoming excessively right-eye dominant; I have to close it when not flying to use my left eye.

– Colors seem to fade in right eye after PNVS flight.

– Sometimes it appears that only my right eye sees what I am viewing. For example, I saw [an object] behind a speaker, reached down to retrieve it, and banged the left side of my forehead on the corner of the speaker.

– My right eye appears to be having acuity problems and suffering from strain. My guess would be that during flight with the HDU/HMD, I may not be able to distinguish a proper focus at infinity as designed, and I'm continually causing my eye to compensate, causing strain and blurring problems [and in the long term] causing my acuity to be lost.

Discussion: The general picture portrayed by these and additional comments is that of a pilot evidencing signs of visual fatigue, spectral adaptation, and either increased or decreased binocular rivalry, with all symptoms attributable to extended periods of night flight with the PNVS/TADS.

D. Aviator spectacle wear:

Do you use the modified spectacles with the HMD? (N=16)	
Yes = 11 (69%)	No = 5 (31%)

If yes, do the modified spectacles interfere with your ability to see the HMD symbology? (N=ll)	
Yes = 10 (91%)	No = 1 (9%)

Comments:

– Eyeglass frame reflects off the combiner lens and cuts out first digit in the torque indicator. Also, I cannot get the HDU close enough to my eye to allow me to see the entire display (the left portion of the right status section, right portion of weapons status in high action display, and occasionally the alt tape on the far right side).

-- The glasses must rest on the HDU which, on occasion, puts the frame in a position where I must look over or under to see the bottom symbology.

-- At times they take away up to half of [the] picture and are constantly slipping down [my] nose regardless of adjustment. At times [they] touch the HDU and [my] eyelashes. [They] had to be bent out of shape to wear. This applies also to laser glasses that pilots with good vision have to wear while in gunnery.

-- The spectacle lens interferes with the ability to properly position the combiner lens the correct distance from the eye in order to see the entire field-of-view -- i.e., the full field-of-view is lost.

Discussion: The modified Apache spectacle presents difficulties to the aviator due primarily to lack of wearing comfort and incompatibility between the spectacle and combiner lens. For many pilots, the net result is the sensation of pressure around the orbit and temples, and a reduced field-of-view.

If you wear the modified spectacles, do you remove the right lens? (N=13)	
Yes = 0 (0%)	No = 13 (100%)

If you do not use the modified spectacles, does the dioptric adjustment on the HDU provide an adequate range of adjustment? (N=13)	
Yes = 13 (100%)	No = 0 (0%)

Discussion: None of the IPs in this study removed their right lens to view the HDU. When not wearing spectacles (or for those spectacle wearers who do not wear spectacles during flight), the HDU dioptric adjustment provides adequate range for image focusing.

E. General discussion and summary:

The results of this questionnaire indicated that more than 80 percent of our sample of AH-64 Apache IPs registered one or more visual complaint(s) associated with flying (either during or after) the Apache aircraft. Many of their comments indicated that symptoms occurred during long flights and/or flying with poor quality or out-of-focus FLIR or display symbology. The most common complaint was that of visual discomfort while flying the aircraft. Fifty-one percent of the pilots indicated that they at least sometimes experienced visual discomfort while flying; only 28 percent reported a similar problem after flying. About one-third of the aviators reported suffering from occasional headaches and about 20 percent responded that they sometimes experienced either blurred vision and/or disorientation while flying. The percentages of pilots reporting headache and blurred vision remained about the same after flight, while the percentage of those experiencing postflight disorientation decreased from 19 percent to five percent. About 20 percent of our sample reported the presence of afterimages following Apache flight.

Fifteen pilots (26 percent of the sample) reported a change in their ability to see or interpret HMD symbology during flight. All but two of those claimed that their abilities worsened. About 70 percent of all pilots used the affirmative categories (Always, Usually, Sometimes) when asked if their vision ever alternated unintentionally between the two eyes either during or after Apache flight. Of the 20 corrective lens wearers, only 11 responded to the question of whether the use of the modified spectacle interfered with the ability to see HMD symbology; of those, however, 10 responded that the spectacles interfered with viewing and caused significant discomfort from their wear.

Post hoc analyses of the questionnaire data indicate no significant relationships between visual symptoms and either total flight hours (all aircraft), recent Apache flight hours, aviator age, years of service, or number of years rated. One interesting trend noted was a relationship between the total number of Apache flight hours and the number of visual complaints both during and after flight. These data, shown in Table 10, indicate that aviators with Apache flight time between 500-1000 hours (an arbitrarily selected range), report fewer visual symptoms than those who have flown either fewer or more hours. The nature of this relationship requires additional resolution --until then, a spurious or nonvisual explanation cannot be ruled out.

Table 10.

Apache flight hours and visual problems

Hours	No. of pilots	Mean age*	Mean no. yrs. rated	Mean no. complaints
< 500	17	34.1	10.6	3.2
500-1000	26	35.3	11.4	2.0
> 1000	12	39.0	17.8	3.4

* in years

Two additional trends require further analysis: (1) the observed differences among the percentages of left- and right-eyed dominants reporting unintentional visual rivalry and (2) the increased incidences of visual symptomology in individuals self-reporting the need to refocus the HMD symbology. Such compensatory refocusing suggests that attempts to set the focus on the HDU may be incorrectly performed by some aviators. This, in turn, could induce accommodative difficulties and, over the course of an extended flight, lead to subjective experiences of visual discomfort. Pilot comments recorded here and additional objective evidence (presented below) lend support to this conclusion.

Part 2: Laboratory Investigation

As part of the evaluation to determine possible visual effects which might be attributable to using monocular helmet-mounted displays, a comprehensive visual functions test battery was completed on volunteer, highly experienced AH-64 aviators. The initial design for the laboratory investigation required two groups of five pilots, one group consisting of individuals who had reported visual problems to the supporting flight surgeon, and a group who had not reported any visual problems and were matched in age and flight experience with the symptomatic group. However, because of other duty conflicts, and at least one refusal to participate, the individuals identified by the flight surgeon as having visual complaints generally were not available for this study. The sample thus consisted of but a single group of opportunistically selected volunteers.

The ten volunteers were all AH-64 instructor pilots assigned to D Company, 1st Battalion, 14th Aviation Regiment, Aviation Training Brigade. The aviator subjects ranged from 32 to 44 years with mean age of 38.6 years, and had 15 to 20 years of military service (mean = 18.25 years). They had been rated aviators for 11 to 20 years (some with prior civilian experience) with a mean of 17.7 years. Their average total flying hours was 4560 hours, ranging from 2800 to 5800 hours. All subjects had substantial previous flight time in the AH-1 helicopter. They had been qualified in the AH-64 aircraft for 48 months on average (range = 16 to 96 months), and their AH-64 flight time ranged from 400 to 1500 hours, with a mean of 895 hours. The subjects estimated that they had logged, on average, 28.7 hours (range = 2 to 50 hours) during the 30 days prior to the study.

Since the test battery used to assess visual function required slightly more than 2 hours to complete, only two subjects were scheduled during a single test period. Six testing stations were established within the laboratory facilities and subjects rotated through these various locations. The visual function testing included assessments of visual acuity, contrast sensitivity, color vision, depth perception, sighting preference, binocular rivalry, and clinical optometric tests of manifest and cycloplegic refractions, accommodative function, and oculomotor status. The procedures used with each of the functional assessments are described briefly below.

a. Visual acuity was measured with the Bailey-Lovie high and low contrast visual acuity charts. These charts consist of 14 rows of 5 letters. Letters on the high contrast chart appear black against the white background and have a nominal contrast of 90 percent, while letters on the low contrast chart appear light gray and have a nominal contrast of 8 percent. Subjects were tested at the standard testing distance of 6 m (20 ft). The high and low contrast visual acuity of each eye was determined separately using different versions of the chart. Chart luminance was approximately 120 fL.

b. The Pelli-Robson contrast sensitivity chart was used to obtain an estimate of contrast sensitivity. This chart consists of eight lines of six letters. All letters are the same size, subtending 0.5* visual angle at a viewing distance of 3 m (10 ft). This letter size is assumed to provide an estimate of contrast sensitivity equivalent to that obtained using sinusoidal gratings of a spatial frequency between 3 and 5 cycles/degree (Pelli, Robson, and Wilkins, 1988).

Within each line of the chart there are two groups, each of three letters. The letters in each group have the same contrast and the log contrast in each successive group is reduced by 0.15. The highest contrast group is in the left half of the top line and the lowest contrast group is in the right half of the bottom line. The chart is read from left to right and from top to bottom.

Each side of the chart contains a different series of letters, so practice effects were eliminated by using one side of the chart when the subject was viewing with the right eye and the other side when viewing was with the left eye. Chart luminance was approximately 132 fL.

c. Color vision was evaluated using the Farnsworth Panel D-15 and Lanthony's desaturated 15 Hue tests. These tests, were designed to allow rapid and easy evaluation of mild or moderate chromatic discrimination loss. The tests consist of 16 color chips selected from the Munsell Book of Color. The hues (Munsell hue) are the same in the two tests and were selected so that the intervals between the different hues are approximately equal, but the purity (Munsell chroma) and luminosity level (Munsell value) are different. In the Panel D-15 test, the mean chroma is about 4.2 and the mean value is about 5; in the desaturated test, the chroma is 2 and the value is 8. As a result, the color chips of the Desaturated 15 hue test appear paler and lighter than those of the Panel D-15 test.

The subject's task in both tests was to arrange the color chips (caps) in order according to color. He was instructed to do this by first locating the color cap that most resembles a reference color cap and placing it next to it, then selecting the color cap that most resembled the last selected cap, etc. until all the caps were arranged in order. Although not specifically recommended for this test, we have adapted the quantitative scoring scheme used for the Farnsworth FM-100 Test, in order to compare small differences in performance in normal observers.

d. Depth perception (stereopsis) was determined using the Armed Forces vision tester (AFVT) and the Randot test. The AFVT is a stereoscope-type instrument incorporating test slides on an illuminated surface. This instrument optically simulates distant and near viewing but only the distant viewing position was used.

The depth perception slide contains six blocks (A-F) with three rows in each block and five rings on each row. For those participants appreciating stereopsis, one of the rings in each row should appear slightly nearer than the other four. The subject's task was to identify the ring which appeared closer.

The Randot test consists of random dot vectographs (super-posed stereoscopic images that give a three-dimensional effect when viewed through polarizing spectacles), containing 10 panels of 3 rings. The subject's task, as with the AFVT, was to identify the ring which appeared closer within each panel. The viewing distance was 40 cm (15.75 in).

e. Sighting preference, a form of ocular dominance, was measured using a battery of five subtests, each being designed to limit visual performance to the use of just one (the "preferred") eye. The composition of the battery was derived from work reported by Coren and Kaplan (1973) who demonstrated significant intercorrelations and factor loading among the tests selected.

All the tests were administered under normal room light with both the examiner and subject standing and facing each other about 10 feet apart. In the pointing test, the subject was asked to extend one arm in front of him at eye height and point to the examiner's nose. The eye with which his finger was aligned then was noted. To avoid the influence of hand preference, the hands were alternated on successive trials. In the alignment test, a cardboard tube 1.5 inches in diameter and 12 inches long was given to the subject. Inside the tube, about 1.5 inches from either end, were one black and one white wire oriented similarly. The subject was instructed to hold the tube with both hands at eye height and, with arms slightly outstretched, visually align the pair of wires. The eye observed by the examiner to be in line with the wires then was recorded. In the hole test, the subject was provided with a 13- X 21-inch card containing a 1-inch hole in its center. Holding the card with both hands at the edges of its long axis, the subject raised the card slowly to eye level and viewed the examiner's head through the hole. The examiner noted which of the subject's two eyes could be seen through the hole. In the Miles ABC test, the subject was provided with a truncated cone having a 4-inch opening on one side and a i inch opening on the other. The subject was instructed to bring the wider end of the cone up in front of his eyes and, using both hands and keeping both eyes open, squeeze the opening wide enough to see the target (the examiner's head) through the smaller aperture. The eye used to observe the examiner was recorded. In the Asher test, the subject was provided with two 8.5- X 10-inch cards, one in each hand. The subject was instructed to bring the cards slowly together in front of his face until he could just see the examiner's nose through the slit between the cards. The examiner recorded the subject's eye observed through the slit.

Each test was administered four times for a total of 20 trials. Trials always began with the arms relaxed and held at the sides (pointing test) or in front of the body. Subjects received a +1 score for each use of the right eye and a -1 for each use of the left. Final scores consisted simply of the arithmetic total of all the trials (possible range of -20 to +20). This scoring procedure yielded graded estimates of both the side and strength of the eye preference.

f. Binocular rivalry, another index of eye dominance, relies on discrepant inputs to the two eyes that cannot be fused easily. Generally the input of one or the other eye is seen for greater durations and that eye is considered the "dominant" of the pair. Two tests were used to assess rivalry.

In the moving gratings test, a vertically scrolling square wave grating (alternating light and dark bars) was produced on a monochrome cathode ray tube (CRT) using the Nicolet CS 2000 contrast sensitivity testing system.* The grating's spatial frequency was set at 3 cycles/degree, its contrast at .95, and its rate of movement at 1 degree/second. The CRT screen was masked with a circular aperture to yield a stimulus grating whose visual angle subtended $1.9^{/}$ at the 3 m viewing distance.

The subject viewed the moving gratings while seated behind a table upon which a Dove (reversing) prism was adjusted to eye height. The subject viewed the CRT unaided with the left eye and through the Dove prism with the right. To the viewer, the individual images appeared as a series of light and dark bars moving in opposite directions (left eye: upward; right eye: downward).

Once seated, the subject was instructed to view the CRT with both eyes open and to indicate the direction and persistence of the grating's movement (upward, downward, or convergent) by pressing and holding down an appropriate key on a hand-held response box. The subject was instructed to initiate a key press with each change in direction and to sustain the key press until a movement in a new direction was perceived.

Each subject received two 60-second trials with the first trial used for practice. A processor was used to record the direction and the duration of each response; hard copy output provided summary data of each of these measures plus cumulative scores.

The second test, the oblique lines test, employed form rivalry to measure eye dominance. On this test, the seated subject dichoptically viewed a stereogram via a table-mounted Keystone Telebinocular. The right eye was presented with a (static) image of a solid black rectangle whose long axis was tilted $45^{/}$ to the right; the left eye received a corresponding image tilted to the left. Both rectangles were equivalent in size (1-5/16 X 7/16 inches) and printed against a white background. The subject viewed the image array with both eyes open and indicated the direction of tilt by using either the left or right keys on a three-key response box (the center key was used to indicate the presence of superimposed images). As in the moving gratings test, two 60-second trials were presented with the first used as a practice trial. Response instructions were similar to that of the gratings test and data recording was similarly processor-controlled.

g. Manifest and cycloplegic refractive errors were measured using standard clinical subjective procedures with a phoropter. Following examination for astigmatic error, the endpoint for spherical refractive error was the maximum positive lens which provided best visual acuity. The cycloplegic refraction, which followed all other visual functions testing, used the same subjective procedures. Cycloplegia was attained using single drops of 0.5% proparacaine hydrochloride, 1% cyclopentolate hydrochloride, and 2.5% phenylephrine hydrochloride followed at a 5 minute interval with an additional drop of 1% cyclopentolate hydrochloride. The drugs were instilled into the lower ocular cul-de-sac. All cycloplegic exams were started 20 minutes after the drugs were instilled.

h. Lateral phorias were measured for fixation distances of optical infinity (6 m) and 40 cm using phoropter-mounted Risley prisms with the dissociating prism to prevent fusion in front of the left eye and the measuring prism in front of the right eye. The subjects' task was to indicate when the targets seen with vertical diplopia were perceived to be vertically aligned. When the measurement distance is optical infinity, thus abolishing both fusional and accommodative reflexes, the test presumably is assessing tonic innervation of the extraocular musculature, and the phoria is considered to be a measurement of the functional position of rest. For distances within optical infinity, the phoria measurement is affected by tonic, accommodative, and psychic (nearness) influences. The phoria measurement particularly is revealing because it can be affected by neurogenic factors, fatigue, ocular distress, and previous ocular history. Phorias are classified in three categories: (1) orthophoria, in which the lines of sight are parallel when testing distance is at optical infinity or the lines of sight are directed at the target positioned at a distance within optical infinity; (2) exophoria, in which the lines of sight are fixated at a point farther away than the target distance; (3) esophoria, in which the lines of sight are converged to a point closer than the test distance.

i. Ocular verqence facility was assessed on all of the subjects using test distances of optical infinity and 40 cm. These tests were accomplished by directing the subjects' attention to the appropriate test target while gradually increasing the amounts of lateral prism binocularly using phoropter-mounted Risley prisms until the subjects reported diplopia (the "break" value). After fusion was lost, the diplopic targets were perceived to continue to move laterally even though no further changes in prism were made as the eyes assumed a position of rest. When the subjects reported that target movement had ceased, the prism values were again reduced binocularly until the subjects reported that the diplopic targets had fused into a single percept (the "recovery" value). Base-out prism stimulates the convergence system, thereby increasing the vergence demand to maintain fusion. The breakpoint, either at optical infinity (convergence) or 40 cm (positive fusional reserve), represents the reserve of the total positive fusional convergence, including the additional assistance of accommodative convergence. In comparison, base-in prism inhibits the convergence system to encourage divergence to maintain fusion. The breakpoint, either at 6 m (abduction) or 40 cm (negative fusional reserve), measures the total negative fusional vergence (divergence) available at the test distance. The recovery values represent the limits of the fusional fields in the appropriate measurement direction.

j. The dissociated cross cylinder test, which measures accuracy of accommodation under monocular viewing conditions, was done at 40 cm. This test uses a lens composed of two cylinders having axes 90/ apart. Fusion is prevented with vertical prism in equal amounts before the two eyes. The principle of the test is to place one meridian of the eye in focus in front of the retina and the other meridian in focus behind the retina. When the subject views a target consisting of vertical and horizontal lines, usually lines of one orientation will appear blacker, or in better focus, than the other orientation. Positive or negative lenses are added in front of the tested eye until the lines in both orientations appear to be equally black or in equal focus. At that point, the two foci are equidistant in front of and behind the retina. The underlying concept of the test is to prevent a clear focus and encourage the accommodation system to relax. While this probably does not occur, in clinical practice it is found that presbyopic patients and patients suffering accommodative fatigue will accept more plus lens power to achieve balance between the two line orientations than will the normal patient.

k. The procedures for testing nearpoint accommodative function, positive and negative relative accommodation, in the present investigation varied slightly from the more usual clinical testing technique. These tests normally are conducted under binocular conditions which presumably assess relationships between accommodation and convergence or accommodative function while maintaining fusion. For the present measurements, tests were conducted on each eye under monocular conditions since the primary interest was in studying differences between the two eyes. Therefore, in practice, we measured accommodative flexibility around the fixation point (40 cm) by introducing positive and negative lenses in front of the tested eye until the subject could no longer compensate for the change in accommodative demand via the lens and reported the target to be blurred.

Results: The delineation of the results of the visual functions assessment follows the order in which the tests were described above.

a. The visual acuities of the sample of Apache IPs are summarized in Table 11. With the high contrast chart, the average monocular visual acuity is about 20/15 for both left and right eye, while, with the low contrast chart, acuity was slightly better when viewing was with the right eye, although right and left eye differences were not statistically significant. The somewhat reduced acuity for low contrast letters was to be expected (Brown and Lovie-Kitchin, 1989).

Table 11.
Bailey-Lovie visual acuity

	High contrast		Low contrast	
	Right eye	Left eye	Right eye	Left eye
Median	20/14.0	20/15.1	20/17.4	20/20.7
Mean	20/14.8	20/14.9	20/18.5	20/20.0
S.D.	3.0	1.1	4.2	3.1
Max	20/11.0	20/12.6	20/13.2	20/15.9
Min	20/21.9	20/16.6	20/28.9	20/26.4

b. Log contrast sensitivity scores obtained with the Pelli-Robson test are summarized in Table 12. There are no norms for this test for the Army aviator population, but the originators of the test found a mean log contrast sensitivity of 1.85 for a group of 30 young graduate students with normal vision. The mean difference between the right and left eye of our sample is not statistically significant.

Table 12.
Pelli-Robson Letter Contrast Sensitivity

	Right eye	Left eye
Median	1.86	1.82
Mean	1.85	1.82
S.D.	0.11	0.10
Max	1.96	1.92
Min	1.70	1.62

c. Performance on the Panel D-15 color vision test was nearly perfect; one subject had a single cap out of correct order while viewing with the right eye and another subject had a single cap out of order while viewing with the left eye. This was not true for the much more sensitive and difficult Desaturated D-15. As seen in Table 13, the mean error score for right eye viewing was 4.7 and for left eye viewing was 5.3. This difference is not statistically significant.

Table 13.
Lanthony Desaturated D-15 test

	Right Eye	Left Eye
Median	5.00	4.17
Mean	4.70	5.30
S.D.	3.50	4.86
Max	10.00	16.00
Min	0.00	0.00

d. The Standards of Medical Fitness, AR 40-501, requires flying personnel to be error free on lines B, C, and D of the depth perception plate of the Armed Forces Vision Tester. All subjects met this requirement. As can be seen in Table 14, the minimum score on the AFVT stereopsis plate was 13 and the maximum was 19; these scores correspond to lines E and F. The mean stereopsis threshold, measured at close distance with the Randot test, was about twice as high as for the AFVT, but no aviator norms exist for this test.

Table 14.
Stereopsis (seconds of arc)

	AFVT (Distance)	Randot (40 cm)
Median	13.06	21.25
Mean	13.60	27.50
S.D.	1.90	12.30
Max	19.00	50.00
Min	13.00	20.00

e. Sighting preference test scores ranged from -20 to +20. Five subjects demonstrated high right eye dominance (scores +18 to +20), and two subjects were left eye dominant (-20). The remaining subjects showed low to moderate right eye dominance (+2 to +12). This distribution resembles that of the population at large (Porac and Coren, 1977).

f. The binocular rivalry scores for each subject were calculated as the percentage of right eye minus left eye observation time. Thus, scores could range from -100 to +100. The obtained minimum and maximum scores as well as measures of central tendency are presented in Table 15, where it may be seen that the ranges of scores on both tests were quite large and that there is a small tendency for right eye dominance. Neither aviator nor population-at-large norms exist for these tests.

Table 15.
Binocular rivalry

	Moving gratings	Oblique lines
Median	5.00	4.00
Mean	2.00	13.80
S.D.	20.39	41.73
Max	27.00	100.00
Min	-35.00	-48.00

g. The spherical equivalent values (sum of spherical error and 1/2 the astigmatic component) for manifest and cycloplegic refractions are shown in Table 16. All numbers are in units of diopters. The average manifest error for our subjects was slightly myopic and slightly greater in the right eye while the average error under cycloplegic conditions was slightly hyperopic and greater in the left eye. The differences between the manifest and cycloplegic refractions were approximately the same in both eyes and equivalent to what might be expected in a routine ocular examination.

Table 16.
Spherical equivalent refraction

	Manifest		Cyclopegic		Difference	
	Right	Left	Right	Left	Right	Left
Median	-0.25	-0.13	+0.25	+0.25	-0.50	-0.38
Mean	-0.23	-0.11	+0.21	+0.31	-0.44	-0.41
S.D.	0.62	0.69	0.77	0.76		
Max	+0.75	+0.75	+1.50	+1.75		
Min	-1.63	-1.75	-1.50	-1.25		

h. The summary results of the lateral phorias measured at optical infinity and 40 cm are shown in Table 17. For this and all other clinical measures, the expected clinical value, i.e. clinical norm, is listed for comparison. While different attempts have been made to establish normative values for various clinical vision tests, we here have adopted those values presented in the classic publications by Morgan (1944a, b) as our expected normal values. The expected lateral phoria measured at optical infinity is slight exophoria, and the mean value among our subjects was slight esophoria in which the two eyes are converged when the fixation target is optical infinity and fusion is prevented. For the 40 cm viewing distance, the mean lateral phoria value was 4.3 exophoria, or slightly greater than the expected clinical norm of 3 exophoria.

Table 17.
Oculomotor function *

At 6.0 meters viewing distance:

	Lateral Phoria	Convergence		Abduction	
		Break	Rec	Break	Rec
Median	0.75 eso	14.0	9.5	6.0	2.5
Mean	0.90 eso	14.0	10.1	5.4	2.4
S.D.	1.46	4.2	3.3	1.0	1.2
Max	4.00 eso	22.0	15.0	6.0	0.0
Min	1.00 exo	8.0	5.0	3.0	0.0
Clin norm	1 + 1 exo	19 +4	10 + 2	7 + 2	4 + 1

At 0.4 meters viewing distance:

	Lateral Phoria	Fusional Reserve			
		Positive		Negative	
		Break	Rec	Break	Rec
Median	3.5 exo	16.0	7.0	18.0	14.0
Mean	4.3 exo	16.8	7.6	16.8	11.8
S.D.	6.0	6.2	3.1	5.6	4.5
Max	9.0 eso	32.0	13.0	23.0	17.0
Min	13.0 exo	8.0	1.0	4.0	3.0
Clin norm	3 + 3 exo	21 + 3	11 + 4	21 + 2	13 + 3

* All measurements are in units of prism diopters.

i. As mentioned previously, each of the ocular vergence tests yields two measured values, i.e., break and recovery. For this study, these tests were termed convergence (base-out prism) and abduction (base-in prism) when the target was placed at optical infinity. With the target at 40 cm, the tests were positive (base-out prism) and negative (base-in prism) fusional reserves. The results for the 10 aviator subjects for each of the vergence tests are shown in Table 17 along with related values and their respective clinical norms. It is noteworthy that, except for the distance convergence recovery value, all of the vergence measures were below the expected clinical norm. The statistical significance of these data will be presented following presentation of the clinical results.

j. The dissociated cross cylinder results, shown in Table 18, are somewhat greater in plus spherical power than the expected clinical value. The median values for the right and left eyes were the same while the average value was slightly greater plus power for the left eye. These grouped values probably reflect the prepresbyopic age of the subjects measured.

k. The positive and negative relative accommodation tests also are displayed in Table 18. As stated previously, since these tests were completed using monocular viewing at 40 cm, the practical implications of the results are in indicating accommodative flexibility when the stimulus demand is presented to one eye. Therefore, while statistical analyses comparing our results to expected clinical norms are shown below, the relevance of such a comparison is equivocal because of the differences in administering the test. A more revealing comparison might be between the left and right eyes (Table 19).

Table 18.
Tests of accommodative function

	Dissociated Cross Cylinder		Relative Accommodation			
			Positive		Negative	
	Right	Left	Right	Left	Right	Left
Median	+0.75	+0.75	-1.37	-1.37	+1.12	+1.50
Mean	+0.85	0.75	-1.50	-1.68	+1.25	+1.50
S.D.	0.56	0.48	0.93	1.03	0.62	0.73
Max	+1.25	1.00	-3.25	-4.00	+2.50	+3.00
min	0.00	+0.50	0.00	0.00	+0.50	+0.50
Clin norm	+0.50	±0.25	-2.37	±0.62	+2.00	±0.25

1. Statistical analyses of the clinical data are presented in Table 19. Table 19A provides the results of one-group t-tests in which the group averages are compared with the expected clinical norms. As indicated by the asterisks, several of the values differ significantly ($p<.05$) from their respective expected value. These primarily are some of the oculomotor tests when the fixation

demand was set at optical infinity, i.e., lateral phoria, convergence fusional break value, and abduction fusional break and recovery values. One additional oculomotor test, positive fusional recovery, also was significantly different from its expected clinical value. Of the accommodative tests, only the right eye values from the negative and positive relative accommodation tests were significantly different (lower) than the expected values.

Table 19B provides matched-pair t-tests in which the right eye values were compared with the left eye values. The Pearson product-moment correlations (R-values) reveal that the right and left eye results were closely related. Although the right eye value was only 0.25 diopters lower than the left eye average for the positive relative accommodation results, the t-test indicates that this has statistical significance (p = .05). The remaining two accommodative tests were not significantly different.

Table 19.
Statistical results

A. One-group t-tests:

	Mean	Clinical norm	P-value
Distance lateral phoria	0.9 eso	1.0 exo	0.003 *
Convergence at 6 meters			
Break	14.0	22.0	0.01 *
Recovery	10.1	10.0	0.93
Abduction at 6 meters			
Break	5.4	7.0	0.001 *
Recovery	2.4	4.0	0.003 *
Near lateral phoria	4.3 exo	3.0 exo	0.53
Positive fusional reserve			
Break	16.8	21.0	0.08
Recovery	7.6	11.0	0.01 *
Negative fusional reserve			
Break	16.8	21.0	0.052
Recovery	11.8	13.0	0.45
Dissociated cross cylinder			
Right eye	+0.85	+0.50	0.09
Left eye	+0.90	+0.50	0.03
Neg relative accommodation			
Right eye	+1.25	+2.00	0.006 *
Left eye	+1.50	+2.00	0.07
Pos relative accommodation			
Right eye	-1.50	-2.37	0.02 *
Left eye	-1.67	-2.37	0.08

B. Matched-pair t-tests

	Rt eye	Lt eye	R-value	P-value
Dissoc cross cylinder	+0.85	+0.90	0.92	0.51
Pos rel accommodation	-1.50	-1.67	0.92	0.23
Neg rel accommodation	+1.25	+1.50	0.94	0.02 *

m. Discussion. The epidemiological appraisal (see Part 1 above) included two questions to assess the frequency that symptoms of visual problems occurred while flying the Apache aircraft (visual discomfort, headache, double vision, blurred vision, and disorientation) or shortly after flying (the same five categories plus afterimages). An index of symptom severity was derived for each respondent by summing each instance that a named symptom was experienced at least sometimes. This severity index provided a possible range of scores of 0 to 11. For the 10 participants of the laboratory study, the range obtained was 0 to 4, with a mean of 1.5. (In contrast, the range of scores for the severity index for the 48 respondents of the questionnaire excluding the 10 laboratory subjects was 0 to 11, with a mean of 2.9.) The Pearson product-moment correlation coefficient was calculated between the symptom severity index and each of 32 measures of visual function. None of the correlations were statistically significant at the 0.05 level for two-tail tests.

Our failure to find a relationship between any measures of an exhaustive visual function evaluation and expression of symptoms associated with flying the Apache could have resulted from the restricted range of scores on the symptom index. Limitations on availability of subjects at the time this study was conducted prevented us from including most of the aviators who complained of visual problems to the flight surgeon. The aviators that we did evaluate cannot be considered entirely representative of the Apache IP population.

Another factor that may have contributed to the lack of relationship between vision measures and complaint scores is the timing of visual function testing. The aviators that we tested came to the Aeromedical Laboratory on a nonflying day after one or more nights of rest. If the bases of visual complaints were transient in nature, recovery might have occurred prior to testing; in this case, a more appropriate experimental design would compare visual function immediately after flying with baseline measures obtained immediately before.

The 12+ hour delay in testing also might have affected our results from the clinical evaluations. Although some of the average values were significantly different from expected clinical norms, they were not greatly different and, if measured on an individual patient, probably would not have been considered clinically significant. However, a pattern emerges when all are considered. Only the right eye, which is presented the HDU information, shows any reduction in accommodative flexibility even though accommodation is presumably a binocular function. Among the oculomotor tests, primarily the measurements made using a fixation distance of optical infinity varied significantly from the expected clinical norm. Perhaps these tests are somewhat suggestive of more clinically significant visual changes which could underlie visual complaints. Possibly, if our subjects had been tested immediately following AH-64 flight operations, they would have demonstrated more profound losses in accommodative flexibility, especially with the right eye, and greater reductions in binocular oculomotor coordination. With only the present data, these suggestions are quite speculative. Our data fail to show visual function changes related to use of the AH-64 HDU. We believe these changes, if any, are quite transient, but we cannot exclude the possibility that our sample of highly experienced aviator subjects did not include individuals having the degree of visual difficulties with the HDU as the more general AH-64 aviator population.

Part 3: Diopter Focus Adjustment of Apache IHADSS

Introduction: Our ability to view objects in sharp focus over a very wide range of viewing distances, from inches to miles, is a product of the accommodative mechanism of the eye. In response to retinal image blur, accommodation is stimulated to change the curvature of the lens and, hence its power, to focus the eye appropriately for a given object distance. When viewing is accomplished with the aid of an optical instrument, such as a telescope or microscope, it is often found that the observer is in a persistent state of overaccommodation, a condition referred to as instrument myopia (Schober, Dehler, and Kassel, 1970; Hennessy, 1975; Ditchburn, 1980). According to Hennessy (1975), instrument myopia has an average value of about 2.25 diopters, with a range of 0.5 to 5.0 diopters.

There is evidence that undesirable, persistent overaccom-modation also characterizes the use of military optical systems. Reinke (1970) found that "the majority of individuals will set the dioptric setting approximately 2.00 diopters more minus power than needed" when adjusting the SU-50 night vision goggles. He cautioned that "long-term accommodative effort often is the cause of headaches and discomfort." More recently, Klm (1982, unpublished results) confirmed that aviators adjusted the AN/PVS-5 night vision goggles dioptric setting so that they were in a state of overaccommodation. The present effort evaluated the helmet mounted display (HMD) dioptric settings made by Apache aviators.

Method: Data on the diopter focus adjustment of the IHADSS HMD were obtained on the flight line during the preflight check. Nine readings were obtained during nighttime illumination, 11 under daytime illumination. The 20 participants, 9 IPs and 11 students (with at least 30 Apache hours), were instructed to go through normal, in cockpit, HMD alignment and focus procedures for infinity focus. The aviator's focus setting of the HMD was then determined with a dioptometer (Coleman, Coleman, and Fridge,1951) mounted in a specially constructed fixture that held the HMD in proper alignment (Figure 3).

Results: The mean focus adjustment was -2.28 diopters, requiring an accommodative effort equal to that amount to compensate for the HMD focus setting. The range of settings was 0 to -5.25 diopters. The settings made by IPs and students were not significantly different nor were those made at night compared to day.

Discussion: Several interpretations have been offered for instrument myopia. One of these interpretations is that instrument myopia is an expression of the resting position of accommodation, that is, the accommodative state of the eye in the absence of stimulation for accommodation such as in the dark (dark focus or night myopia) or in a Ganzfeld (empty field myopia). Evidence for this point of view was obtained by Hennessy (1975), who had 15 young emmetropic observers focus a microscope while he simultaneously measured their refractive state. His subjects overaccommodated 1.91 diopters on average, with a range of 0.96 diopters underaccommodation to 2.78 diopters overaccommodation. In addition, Hennessy measured their dark focus and the correlation coefficient was 0.78 between the two sets of measurements, from which Hennessy concluded that "instrument myopia and resting state of accommodation are manifestations of the same phenomenon" (p. 1118). Further evidence derived from an ancillary study in which Hennessy varied the method of focus. Twenty-two emmetropic subjects viewed a target through a microscope using three methods of focus: myopic focusing (i.e., from a position that should tend to

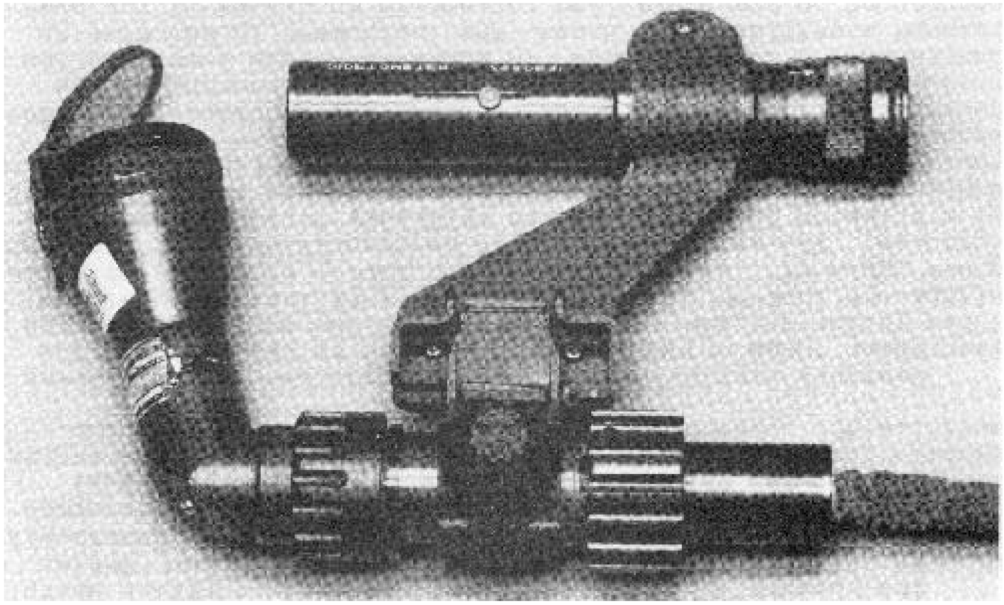

Figure 3. Apparatus used to determine pilot's HMD diopter focus settings

induce accommodation), hyperopic focusing (from a position that should not tend to induce accommodation), and oscillatory focusing (free adjustment of focus as desired). The amount of overaccommodation for the three focusing methods were: myopic, 2.19; oscillation, 1.95; hypetopic, 1.75. Thus, accommodation responded only weakly to variation of image focus while the microscope was being adjusted; the large overaccommodation reflecting the intermediate resting state of accommodation.

The results of Hennessy's ancillary study contrast sharply with those previously obtained in a study by Schober, Dehler, and Kassel (1970), in which method of focus also was systematically varied. In that study the corresponding amounts of overaccom-modation for the three focusing methods were: myopic, 5.2; oscillation, 3.0; hyperopic, 2.4. Thus, in this study, accommodation did respond strongly to image focusing adjustment.

Hennessy attributed the low accommodative responsiveness to instrument focus adjustment in his study to two factors. The first factor was the very small size of the exit pupil of the microscope that he used, which was 2 mm or less, thus affording great depth of field of the eye, and little stimulus for accommodation. The second factor that he identified was the absence of a stimulus for accommodation by highly defocused images. Under these conditions the eye tends to assume its intermediate resting state of accommodation. According to Hennessy, "As the instrument is adjusted, a point is reached where the image becomes sufficiently in focus to stimulate accommodation. But, then, because of the rapidity of the manual focusing of the instrument, a focused image is achieved before accommodation can respond significantly. Hence, the instrument is adjusted to correspond to the prevailing refractive condition of the eye" (p.1119).

The interpretation of instrument myopia as reflecting the resting position of accommodation is not a tenable explanation for the observed misfocusing of the Apache HMD. In the first place, the HMD exit pupil is 10 mm, completely filling the natural pupil of the eye under all prevailing illumination levels, so there is no enhancement of the depth of field of the eye. In the second place, focus adjustment is accomplished by means of a fine thread, multiturn focusing ring, so that focusing is quite slow. For the HMD, accommodative responsiveness to focus and the correlation coefficient was 0.78 between the two sets of measurements, from which Hennessy concluded that "instrument myopia and resting state of accommodation are manifestations of the same phenomenon" (p. 1118). Further evidence derived from an ancillary study in which Hennessy varied the method of focus. Twenty-two emmetropic subjects viewed a target through a microscope using three methods of focus: myopic focusing (i.e., from a position that should tend to induce accommodation), hyperopic focusing (from a position that should not tend to induce accommodation), and oscillatory focusing (free adjustment of focus as desired). The amount of overaccommodation for the three focusing methods were: myopic, 2.19; oscillation, 1.95; hyperopic, 1.75. Thus, accommodation responded only weakly to variation of image focus while the microscope was being adjusted; the large overaccommodation reflecting the intermediate resting state of accommodation.

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The more desirable method of focus is the hyperopic method, which is to start with the focusing ring in the extreme plus position (virtual image beyond infinity, hence blurred), and to rotate the focusing ring just to the point where the image is in sharp focus. Further rotation only stimulates over accommodation and does not improve image sharpness. Although we did not manipulate focusing methods systematically, we did ask three pilots to repeat their adjustment of the infinity focus using the hyperopic focus method and all were between 0 and I diopter of over accommodation. Information on proper focus adjustment of the Apache HMD has been disseminated to the operational community (Behar and Rash, 1990).

Since most aviators are emmetropes, it would be desirable if a reference mark or detente existed on the focusing ring to indicate the point of zero diopters, which corresponds to imagery at infinity for the normal eye. We have no actual evidence that flying the Apache with the HMD adjusted so that the eyes are in a state of persistent over accommodation causes or contributes to visual fatigue, discomfort, headaches or other complaints but we believe it is very likely. If nothing else, since accommodation is consensual, when the right eye is over accommodated, the left eye is out of focus for out-of-the-cockpit viewing, contributing to the often reported high visual workload involved in flying this aircraft.

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Appendix A

Aviator questionnaire

USAARL SURVEY OF APACHE AVIATORS

Purpose: The purpose of this questionnaire is to assess the visual status of AH-64A Apache pilots. The information that you provide will help us to identify and evaluate any visual problems that you've experienced personally.

Your Responses: It is important that you answer the questions as accurately and fully as possible. Your responses will provide information that could be used to improve current equipment and improve the design of future electro-optical systems and aircraft.

Anonymity: Both you and your responses will remain anonymous. The data collected will be used for research purposes only. They will not become part of your record, nor will they be used to make any determination about you.

Thank you for your help.

1. General

Date:_______________ Age_____ Years of service___________

2. Aviation Experience:

a. Year first rated ____________ Total flight hours _____________

b. Aircraft qualified to fly: Approximate No. of Hours:

c. Apache hours during the last 30 days _______________

3. Vision History:

a. Have you ever been prescribed eyeglasses? Yes No

If yes, age when first prescribed __________,
date of most recent prescription ___________

If yes, reason for glasses ____
(For example, for distance, for reading/close work, all- the-time, flying only)

b. Have you ever worn contact lenses?
Never_________
Previously but discontinued _________
Presently wear contacts___________

c. Have you ever been treated for an eye disease or an eye injury? If yes, explain
____

d. Have you ever experienced double vision? Yes ____ No _____
If yes, when?____________ Please explain________________________________
____

e. Have you ever experienced temporary reduced visual acuity (blurred vision)?
Yes___ No _____
If yes, when?_______________How long?____________
Please explain ___________________________

f. Do you get headaches from extended periods of close work, for example, reading small print? Yes_________ No _______________

g. Do you ever experience eye-strain? Yes _____ No ______
When? ___________________________________

h. Which is your better eye (preferred sighting eye)?
Left_____ Right_____ Equal _____ Don't know_____
Which eye would you use with a telescope?________
Which eye would you use to see through a keyhole? _______
Is your better eye the same one as prior to AH-64A training? ________________

i. What is your hand preference for ball throwing?
Left_____ Right_____ Ambidextrous (evenhanded) ___________

4. Aviation Vision:

a. Are you NVG qualified? Yes _______ No__________
If yes, approximate number of NVG flight hours _______________

b. When were you Apache qualified? _______________________

c. What percent of time have you recently flown the pilot position?________________, the CPG position?________________

d. How satisfied are you with the fit of your IHADSS helmet?
Not at all_________ Somewhat________Reasonably________Perfectly_________

If less than perfectly satisfied, please describe any problem the fit causes:
____

e. While flying the Apache, have you experienced:

Visual discomfort:	Never_____	Sometimes_____	Always_____
Headache:	Never_____	Sometimes_____	Always_____
Double vision:	Never_____	Sometimes_____	Always_____
Blurred vision:	Never_____	Sometimes_____	Always_____
Disorientation:	Never_____	Sometimes_____	Always_____

If other than never, please comment on how often, how long it persists, and how severe it is:
____
____

f. After flying the Apache, have you experienced:

Visual discomfort:	Never_____	Sometimes_____	Always_____
Headache:	Never_____	Sometimes_____	Always_____
Double vision:	Never_____	Sometimes_____	Always_____
Blurred vision:	Never_____	Sometimes_____	Always_____
Disorientation:	Never_____	Sometimes_____	Always_____
After-images:	Never_____	Sometimes_____	Always _____

If other than never, please comment on how often, how long it persists, and how severe it is:
____

g. Have you noted any change in your ability to see or interpret the HMD symbology during any phase of flight? Yes _______ No________
If yes, please explain____
____

h. When viewing through the HMD, can you focus clearly on the external scene and symbology simultaneously?
Always _____ Usually_____Sometimes______Never_______
Do you have to refocus to view the symbology? Yes______No______

i. How do you use your visor? Day: Up_____ Down _____
Night: Up_____ Down ______

j. During Apache flight, does your vision sometimes unintentionally alternate between the two eyes?
Always _____ Usually_____ Sometimes_____ Never_____

k. After Apache flight, does your vision sometimes unintentionally alternate between the two eyes?
Always _____ Usually______ Sometimes______ Never ________

1. Please comment on other visual or ocular symptoms you have experienced with the Apache IHADSS:
____
____
____
____

FOR SPECTACLE WEARERS ONLY:

m. Do you use the modified spectacles with the HMD?

Yes _____ No _____

If yes, do the modified spectacles interfere with your ability to see the HMD symbology?

Yes _____ No_____

If yes, please explain____

n. If you wear the modified spectacles, do you remove the right lens?

Yes_____ No_____

o. If you do not use the modified spectacles, does the dioptric adjustment on the HMD provide an adequate range of adjustment?

Yes _____ No_____

p. If you do not use the modified spectacles, do you experience any difficulty when viewing cockpit instruments?

Yes ______ No_____

If yes, please explain _______________________________________

q. If you do not use the modified spectacles, do you experience any difficulty when viewing outside the cockpit.

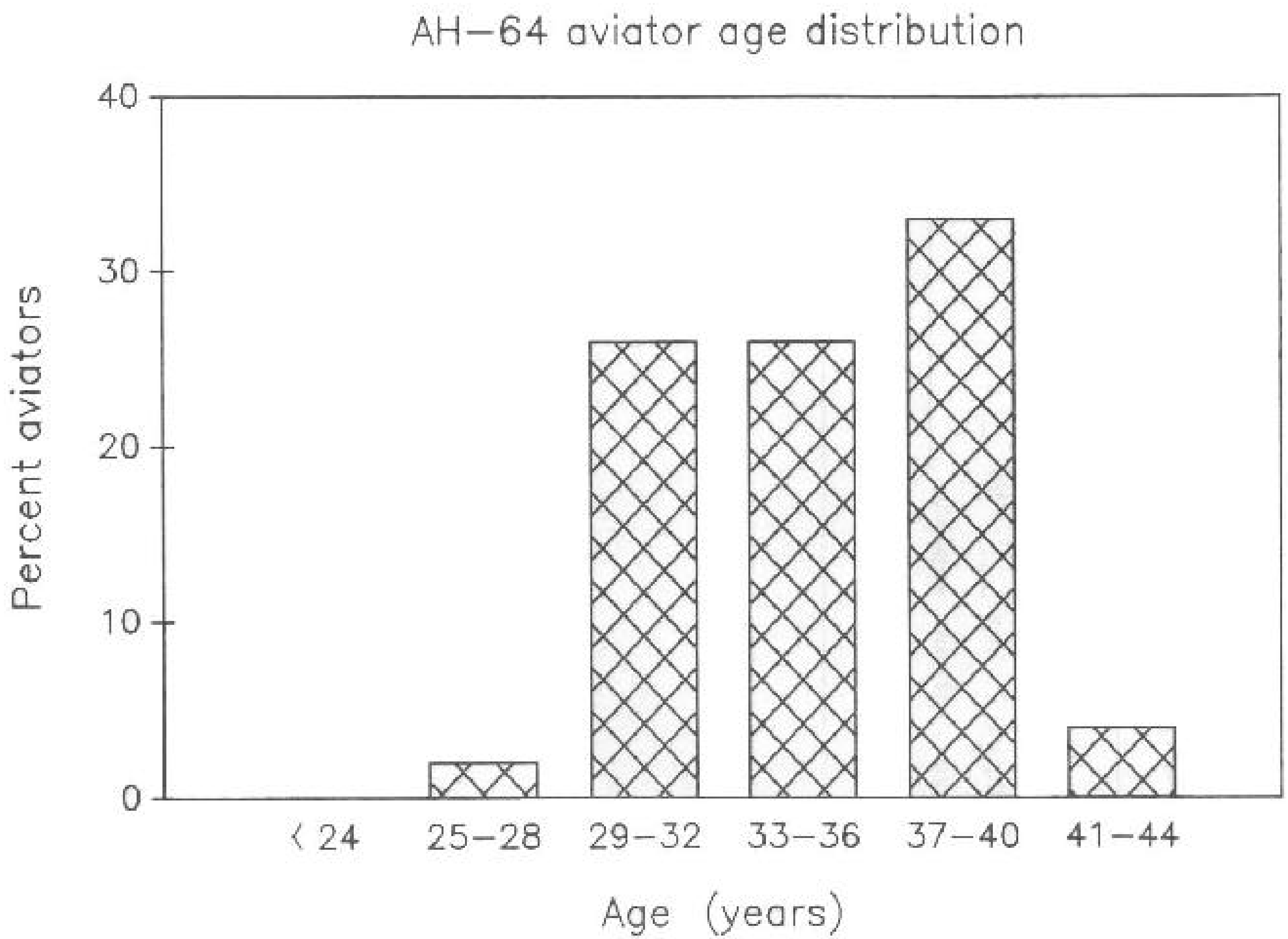
Yes _____ No______

If yes, please explain____

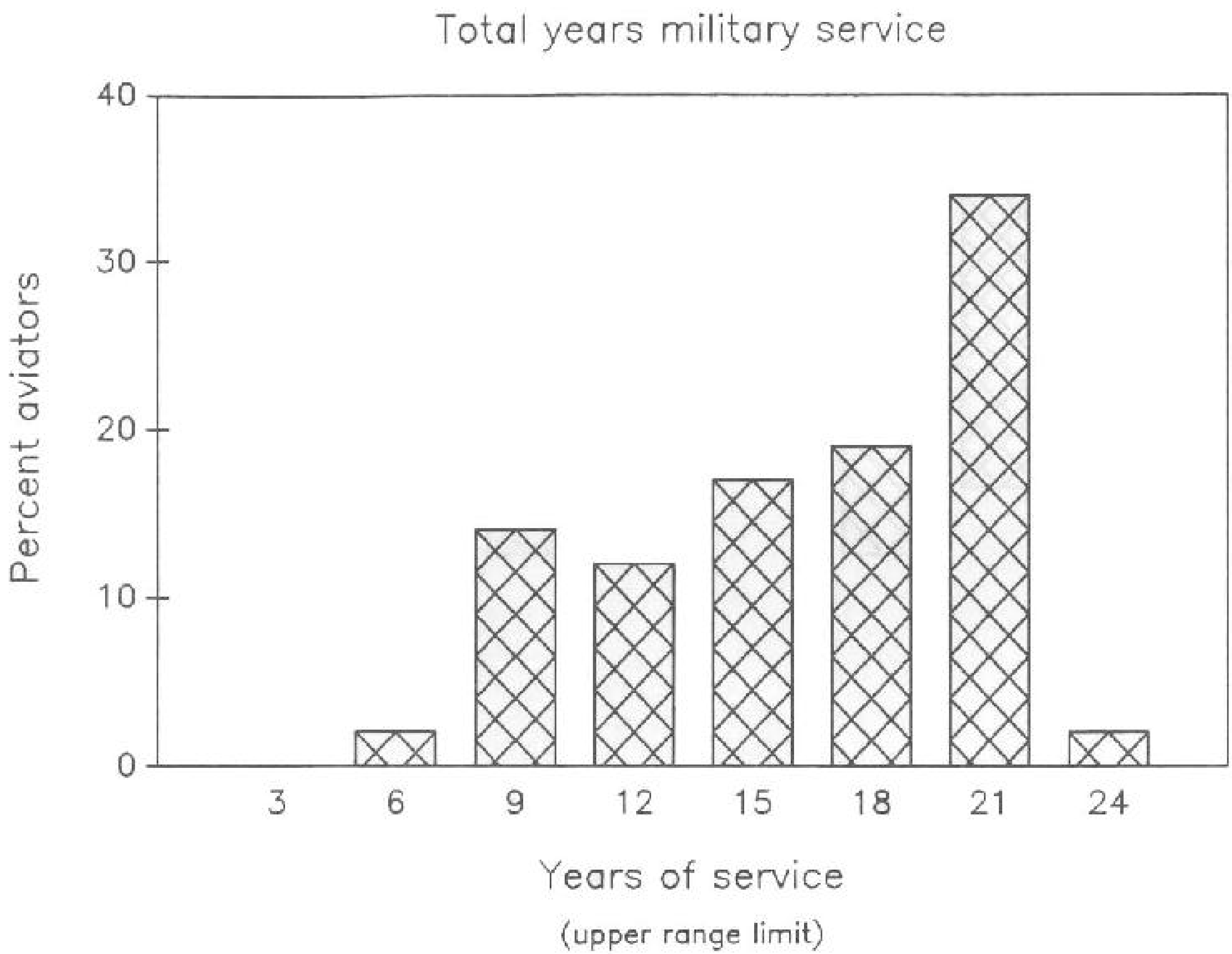
____

____

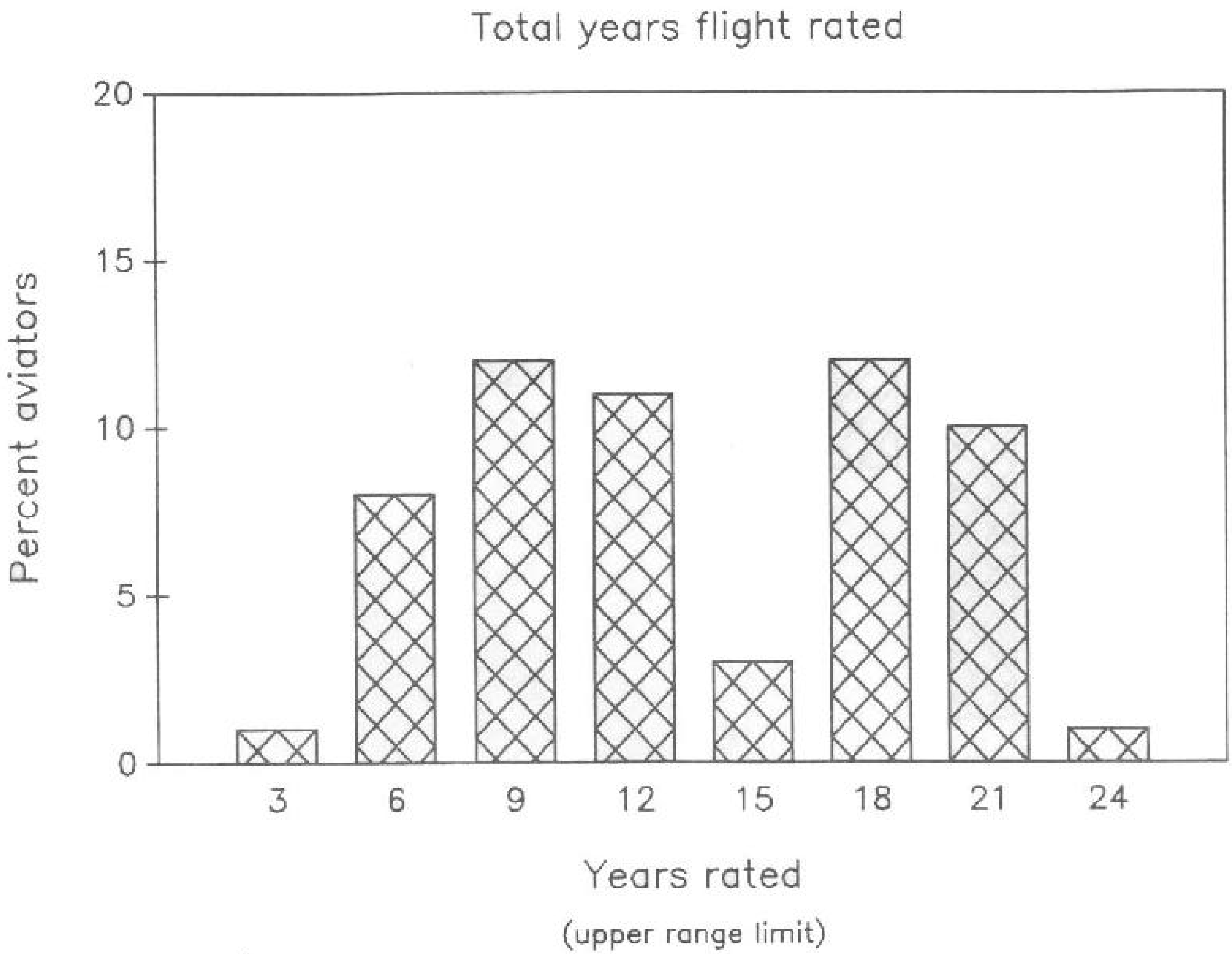
Appendix B.


AH-64 aviator age distribution
40
30
20
10
0
Percent aviators
< 24
25-28
29-32
33-36
37-40
41-44
Age (years)

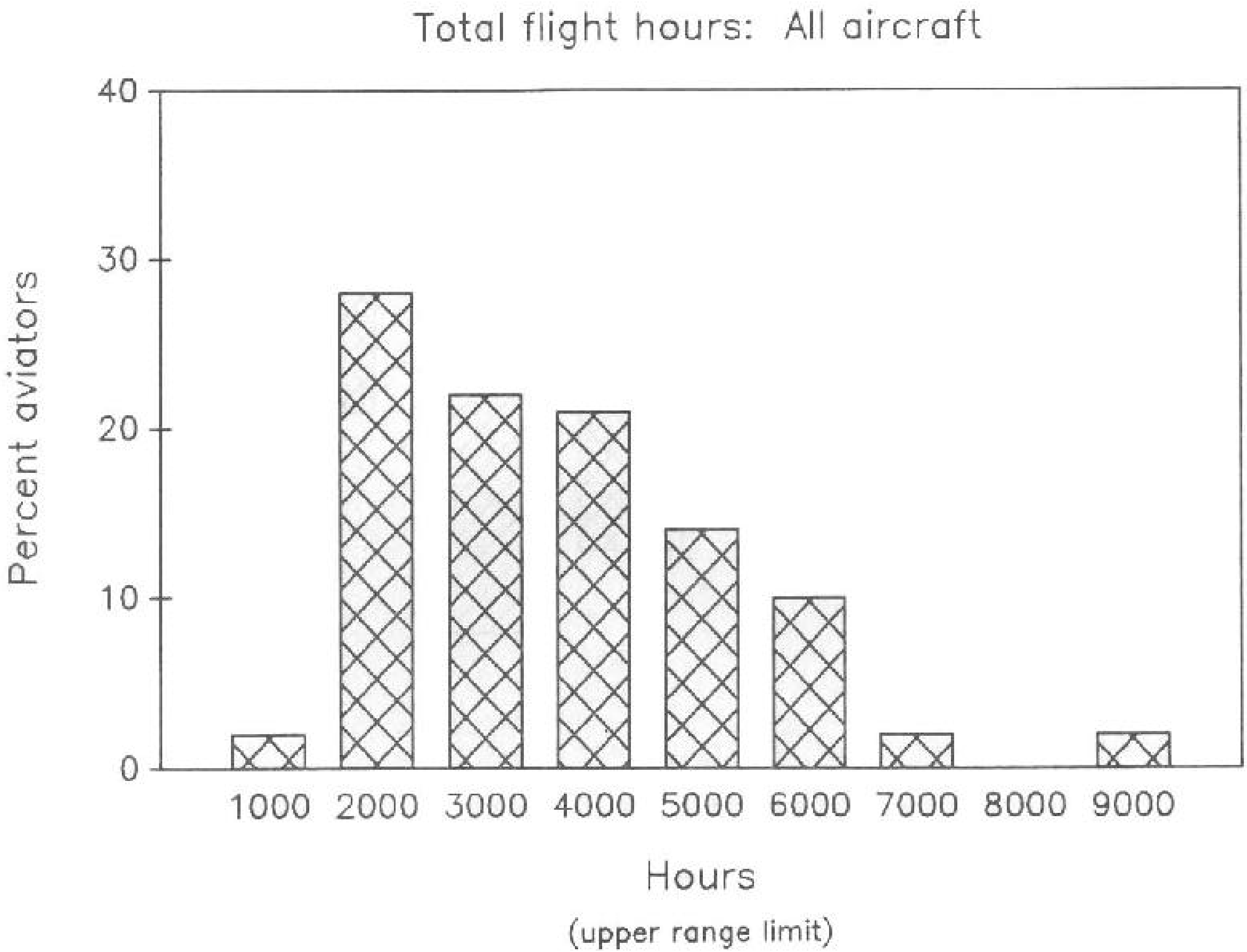
Appendix C.


Total years military service
Percent aviators
40
30
20
10
0
3
6
9
12
15
18
21
24
Years of service
(upper range limit)

Appendix D.

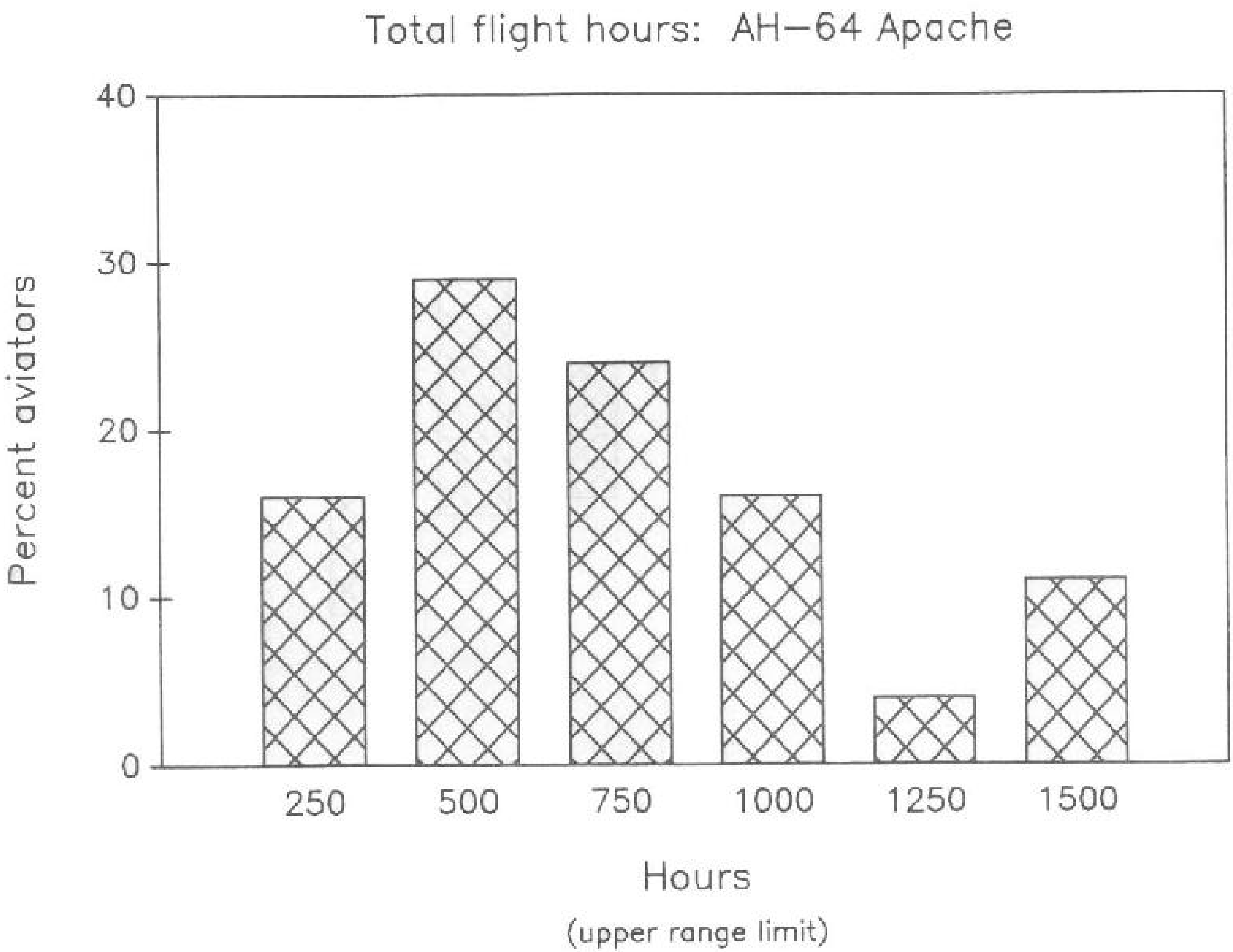

Total years flight rated
Percent aviators
0
5
10
15
20
3
6
9
12
15
18
21
24
Years rated
(upper range limit)

Appendix E.



Total flight hours: All aircraft
40
30
20
10
0
Percent aviators
1000 2000 3000 4000 5000 6000 7000 8000 9000
Hours
(upper range limit)

Appendix F.


Total flight hours: AH-64 Apache
Percent aviators
40
30
20
10
0
250
500
750
1000
1250
1500
Hours
(upper range limit)

Appendix G

List of manufacturers

Nicolet Biomedical Instrument Corporation
5225-4 Verona Road
P.O. Box 4287
Madison, WI 53711-0287